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5A.20 Sensitivity of the tropical ocean-atmosphere to seasonal and long-term climate forcing p4

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1. Introduction

Since the pioneer works of Bjerknes (1966,1969) many studies have been conducted to understand the El Nino and Southern Oscillation (ENSO) phenomenon. These studies have led to a basic understanding of the dynamics of El Nino. Central to the couple dynamics of ENSO is the delayed action oscillator theory (Suarez and Schopf 1988), which successfully describes the cyclic feature of El Nino. While the oscillatory feature of El Nino is reasonably well understood, the irregularity of El Nino, the effect of monsoon on ENSO, and the response of coupled system to the global warming are still under debate.

In the present study, we attempt to provide some theoretical understanding of possible impacts of seasonal cycle, monsoon, and climate changes on ENSO using intermediate coupled model.

2. Model

The atmosphere-ocean coupled model used in this study is described in Zebiak and Cane(1987). The model consists of the ocean whose evolution is determined prognostically and the atmosphere which is determined diagnostically as a function of sea surface temperature. Both atmosphere and ocean model describe anomalies about a specified monthly varying mean state.

The model ocean consists of an upper layer overlying a deep water. To simulate the surface wind driven currents, a fixed depth surface layer is added to the top of upper layer. The thermocline depth anomalies and depth averaged currents are governed by linear shallow water wave dynamics. But SST is determined by the temperature advection by surface currents, upwelling, and heat flux to the atmosphere.

The atmosphere model is the steady-state linear shallow water model on an equatorial beta plane(Gill 1980). The forcing of the model atmosphere is represented by the local heating associated with SST anomalies and the low level moisture convergence determined by the surface wind convergence. Since the local heating depends nonlinearly on the mean SST and the low level moisture convergence proportional to the mean convergence, the coupling between atmosphere and ocean depends on the annual cycle. The details of CZ model is described in Zebiak and Cane(1987) and Zebiak(1982,1986).

3. Effect of Seasonal Cycle on the Model El Nino Evolution

In order to examine the influence of seasonal cycle on the evolution of El Nino, the prescribed mean states are divided into two components, phase and amplitude. Because CZ model describe anomalies and the mean state is prescribed, it is easy to study the effect of phase and amplitude of seasonal cycle separately. In this study the effect of phase are investigated with the perpetual simulation of CZ model and the effect of amplitude are investigated with the increased or decreased amplitude of specified mean annual cycle.

3.1 Phase of Seasonal Cycle

The CZ model requires specified seasonal cycle in five variables. They are the climatological monthly mean SST, surface currents, upwelling velocity, surface winds, and surface wind divergence. In order to investigate the effect of the mean state on the model El Nino, 12 experiments are performed. In these experiments, all five mean states are fixed for each of the 12 calendar month. For each experiment, the model start from mean state and the integration procedure is same as in the standard run except for the fixed mean state.

Figure 1 shows the time series of NINO3 SST anomalies obtained from each experiments.

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Even in the absence of seasonal cycle, the evolution of model El Nino shows aperiodic behaviour for some mean states. Time scales of interannual variations in the model are varied as the mean states. Interestingly, the most dominant period of model El Nino increase as the degree of complexity of the time series of NINO3 SST anomalies. In the experiment with March mean condition, the peak power appeared around 4 year period. However, for July mean conditions, the distinct peaks appeared around 8 year period as well as 4 year period. However, boreal winter and autumn conditions are not sufficient to produce any interannual variations in the model.

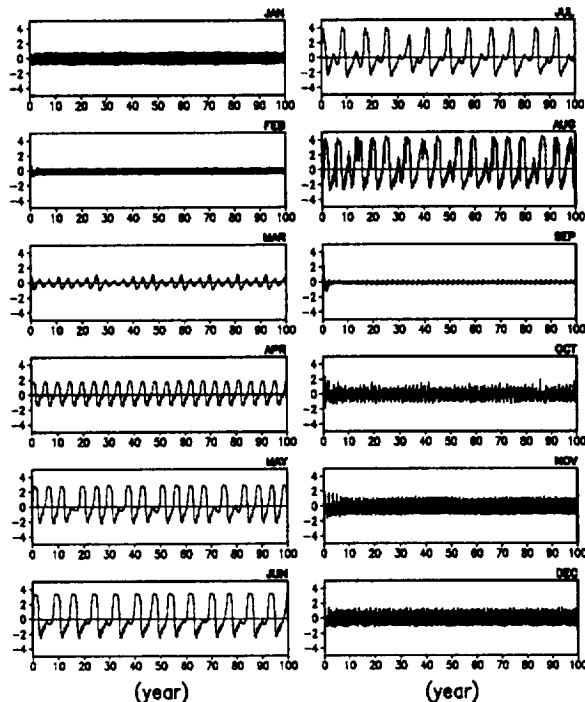


Fig.1 Time series of simulated SST anomalies over the NINO3 region with the mean state of the 12 calendar month

Composite charts(not shown) for two experiments done with January and July mean conditions give some possible explanation for the time scales of model El Nino. For the experiment with January mean condition, the variation of model SST and thermocline depth anomalies are confined near the equator and the evolution of thermocline depth anomalies clearly shows the westward propagating Rossby waves in the off-equatorial region centered at 5N and 5S. These Rossby waves determine the time scales of the variations. In the experiment with July mean conditions, however, model El Nino shows more meridionally extended structure,

especially in the thermocline depth anomaly fields. Since the propagation speed of the off-equatorial Rossby waves are determined by the location in latitude(Kessler 1991), the meridional structure of the thermocline depth anomalies might be one of the possible mechanism responsible to the time scales of El Nino. Since more meridionally extended structure can generate more diverse Rossby waves with different phase speed, the results show more chaotic features. And this structure seems to be related with the mean state of the model. However, because the efficiency of the Rossby wave components outside of equatorial band are very low(Kessler 1991), more careful studies are needed to support this explanation.

3.2 Amplitude of Seasonal Cycle

To vary the amplitude of prescribed mean states, the new annual cycle, $M(t)$, are defined as following.

$$M(t) = m + a(m(t) - m)$$

$m(t)$ is the monthly varying mean state used in the control run and m is the annual mean climatology of $m(t)$. The parameter a specifies the amplitude of the seasonal cycle. When a is equal to 1, the seasonal cycle in the model is same as in the control run.

To investigate the effect of amplitude of seasonal cycle on the model El Nino, the parameter a is varied from 0.4 to 2.6. The results showed that the model El Nino exhibits aperiodic behavior for a whole range of the amplitude of seasonal cycle except for very weak seasonality less than 0.2(not shown). Fig. 2 shows the power spectral density of NINO3 SST anomalies for selected experiments. The amplitude of model El Nino increases as the amplitude of seasonal cycle increase. However, the period of model El Nino is shortened as increasing the seasonality. For extremely increased seasonality, the model gives up the intrinsic variability and has two distinct spectral peak at the periods of 1 and 2 year. As in the perpetual simulations, With increasing seasonality, the meridional structure of SST is more confined to the equatorial region with increasing seasonality.

4. Effects of Westerly Winds Anomalies in the Western Pacific on the Model El Nino

Due to the limited domain and lack of land surface physics, the model used in this study does not have external forcing which is

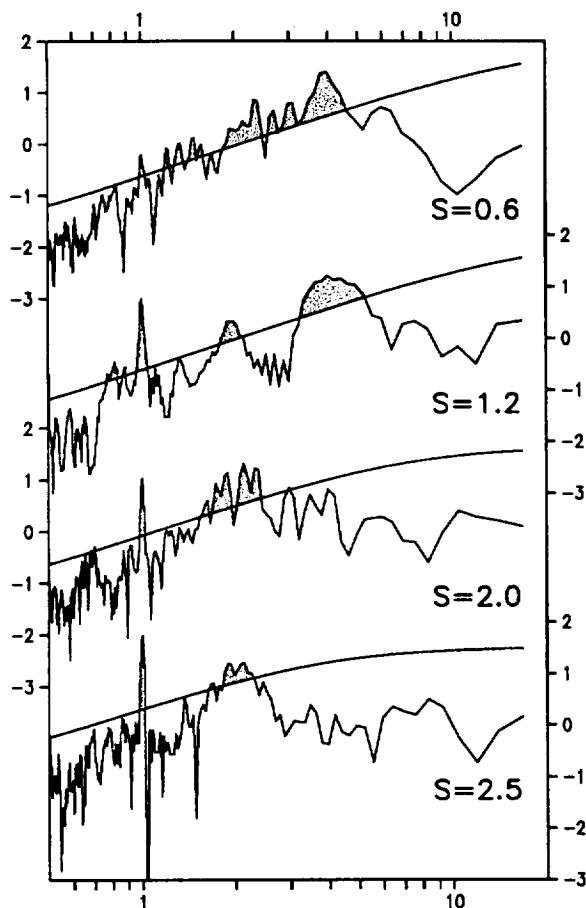


Fig.2 Power spectra of NINO3 SST anomalies as a function of the intensity of seasonal cycle.

related with Asian monsoon. To introduce monsoon related forcing over western Pacific region, the anomalous monsoon flow is parameterized as a function of NINO3 SST with time lag. To clarify the effect of monsoon flow, the zonal winds anomalies are only used for external forcing. A new factor is introduced to modulate the strength of anomalous monsoon flow. This factor represents the coupling intensity between monsoon and El Nino. And this factor also indicates the intensity of anomalous westerly winds over the western Pacific. The factor 1.0 is corresponding to about 1.3 m/sec of area averaged winds speed over the western Pacific when NINO3 SST anomaly is 3K.

Six month lag means that the easterly anomalies are added after 6 month from the mature phase of El Nino. This relation reflects the fact that a strong summer monsoon follows the center of a warm event by El Nino in observation (Yasunari 1990, Webster and Yang 1992, Lau and Yang 1996). On the other hand,

lag 0 means a weak winter monsoon during the mature phase of El Nino.

Interannual variation in the model is rapidly damped out when the lag is 1, 2, or 3 month. Many previous studies including this one show that the evolution of El Niño obtained from CZ model is very similar to that of the delayed action oscillator theory. According to the theory, the wind stress curl anomalies on the off-equatorial region of central and western Pacific are crucial for the cyclic feature of El Niño. However the external forcing introduced in this study reduce the wind stress curl induced by warm SST in the eastern Pacific during El Niño.

The results are summarized in Fig. 3. Fig. 3 shows the period of the most dominant oscillations of each experiments. Overall, the external forcing shorten the period of model El Nino compare to standard run. For lag greater than 3 month, the period of model El Nino is shorten with increasing intensity of external forcing and the period seems to be saturated around 2 year. However, in real atmosphere-ocean coupled system, the location of maximum westerly winds anomalies in the western Pacific is not appeared at equator but between 5° N - 10° N. Therefore the effects of westerly winds on El Nino are more complicated.

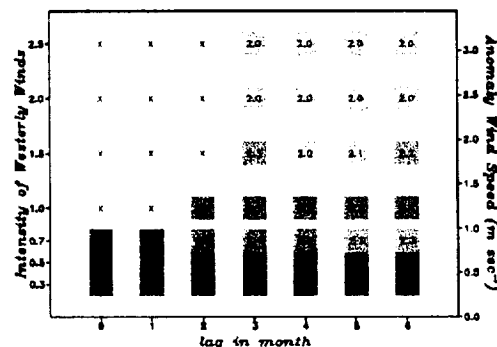


Fig.3 Period of the most dominant oscillation as functions of lag and the intensity of westerly winds anomalies superimposed over the western Pacific.

5. Response of Model El Nino to Cold-tongue Change

The effect of the change of the mean thermocline depth on ENSO variability is investigated. As a first step, the variation of cold tongue is only considered. Time series of the simulated El Nino index is very chaotic and most sensitive to the zonal extend of cold tongue and/or the mean depth of equatorial eastern

Pacific. When the cold tongue is extended to the central Pacific and/or the mean depth of equatorial eastern Pacific ocean is shallow, El Nino index shows very distinctive quasiperiodic features. On the other hand, model El Nino is damped out when the cold tongue is shrunk.

6. Conclusion

Using the simple atmosphere-ocean coupled model, the effect of seasonal cycle, monsoon, and climate change on the evolution of El Nino are investigated. The results indicate that northern spring and summer mean conditions in the tropical atmosphere-ocean provide a favorable basic state for interannual variations of sea surface temperature(SST) in the eastern Pacific. A strong seasonal cycle shortens the periodicity of El Nino but intensifies its amplitude.

The external wind forcing superimposed over western Pacific region reduced the wind stress curl generated during the mature phase of El Nino. Therefore the evolution of El Nino is accelerated and the period of El Nino is shortened. When the forcing is increased, the evolution of El Nino shows QBO like feature.

The effect of the change of cold-tongue on the El Nino cycle is also studied. The periodicity and amplitude of model El Nino are very sensitive to the zonal extend and mean depth of cold-tongue.

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